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INCORPORATION OF PRIVACY ELEMENTS IN SPACE STATION DESIGN

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ABSTRACT

Privacy exists to the extent that individuals can control the degree of social contact that they have with one another. The opportunity to withdraw from other people serves a number of important psychological and social functions, and is in the interests of safety, high performance, and high quality of human life. The present paper reviews privacy requirements for Space Station crew members, and suggests architectural and other guidelines for helping astronauts achieve desired levels of privacy. This report discusses, in turn, four dimensions of privacy: the separation of activities by areas within the Space Station, controlling the extent to which astronauts have visual contact with one another, controlling the extent to which astronauts have auditory contact with one another, and odor control. Each section presents a statement of the problem, a review of general solutions, and specific recommendations. The report concludes with a brief consideration of how selection, training, and other procedures can also help Space Station occupants achieve satisfactory levels of seclusion.

EXECUTIVE SUMMARY

This paper examines the design implications of Space Station astronauts' needs for privacy. Privacy exists to the extent that individuals can control the amount of contact that they have with one another. Privacy helps people achieve focus or concentration, contributes to "rest and recuperation" and thereby reduces stress, reduces social tensions, and makes it possible for members of small groups of people to interact with one another in a candid manner. Spaceflight and other isolated and confined environments can at once increase people's privacy requirements and make such requirements more difficult to satisfy.

Several factors complicate the task of providing privacy aboard the Space Station. There is no ideal level of privacy: optimal privacy depends upon such variables as location, activity, and personal preferences as determined in part by gender, culture, and other variables. Furthermore, volume and weight restrictions, reliance on semi-closed life support systems, the need for flight qualified materials, microgravity, and other considerations constrain the range of viable mechanisms for limiting social intrusion aboard the Space Station.

Four sections of this report address, in turn, locational, visual, auditory, and olfctory privacy. Within each of these sections we consider the problems, discuss general solutions, and offer specific recommendations. We conclude the report with a brief consideration of how selection, training, and other mechanisms which have little or no impact on actual Space Station design may help occupants achieve satisfactory levels of privacy. In all cases, empirical testing in high fidelity mockups is required to determine the effectiveness of the proposed recommendations. We also urge continuous post-occupancy evaluation to refine the privacy guidelines over successive generations of space habitats.

Locational privacy refers to the control of social intrusion through regulating the distribution of individuals within physical space. This includes both the physical separation of activity areas, and the spacing of occupants within an area. Specific areas within the Space Station should be geared to activities which are arranged along a privacy continuum. At one end of this continuum will be sleeping quarters and personal hygiene facilities which afford the highest possible degree of privacy. At the other end of the continuum will be the ward room, which is open to all comers. Within an area, it is essential to ensure that astronauts have ample space

to perform all tasks without physically or socially interfering with one another and that tney have the means to vary the amount of contact that they have with one another.

1. All spatial dimensions should be determined in accordance with the social as well as the physical requirements of the task.

2. Each astronaut should have an individual sleeping area.

3. Personal crew quarters should be of sufficient size to permit the largest prospective crew member adequate space.

4. Crew quarters should be self-contained.

5. Except in emergencies, inhabitants should have exclusive and final control over access to their quarters.

6. Allowance s! !d be made for the storage of personal possessions in private quarters.

7. Entrances to opposing individual sleeping quarters should be staggered.

8. Crew quarters should be large enough to accommodate two individuals for brief periods of time.

9. Multiple personal hygiene facilities should be available.

10. There should be a library, study, or other area that can accommodate small groups of astronauts.

11. At least one area should be large enough to accommodate the entire crew.

12. Adequate clearance should be provided at all work stations.

13. Work stations should be staggered.

14. At each work station, storage areas should be provided for all materials and tools and at least one secure storage space should be provided for each crew member whc is expected to use that work station on a regular basis.

15. Areas where face-to-face communication is expected should be at least 1.7 m in width to permit effective interaction. Public access areas should allow at least .30 m to .45 m around each user.

16. Movable panels and screens should be made available to expand and contract work, living, and recreational areas.

17. Movable or rearrangeable furnishings encourage the redefinition of areas to include greater or lesser numbers of people.

18. The allocation of personal or quasipersonal territories should be based on needs as defined by work assignments, and should not be distributed or revoked as rewards or punishments.

19. All pieces of equipment, restraints, and aids should be adjustable and relocatable to accommodate anthropometric variations and personal preferences.

20. Positioning devices must make it possible for astronauts to move normally without colliding with one another.

21. Positioning devices should encourage interaction on the same horizontal visual plane.

Visual privacy is achieved to the extent that it is possible to control one's visibility to other astronauts, and to restrict other astronauts from entering into one's own field of view. Visual privacy is of course guaranteed by walls and doors. However, it is possible to offer visual privacy without resorting to these "hard" architectural features. Environmental qualities which enhance perceived spaciousness tend to reduce impressions of crowding and increase a sense of privacy. Within an area, occupants' angles of orientation relative to one another affect privacy. Windows, works of art, and other distractors which divert attention from other people can promote social distance. Variations in lighting are another consideration. Also, privacy is affected by surveillance and communication systems which allow social intrusion independent of sheer physical distance and the existence of walls or other architectural barriers.

22. Relatively light, pale, or desaturated colors are recommended for interior walls since they tend to create an impression of spaciousness.

23. Horizontal layouts are superior to vertical layouts since they produce greater impressions of spaciousness.

24. Irregular interior shapes are recommended because they appear more spacious than do interiors that are arranged in common and simple geometric patterns.

25. Each individual work station should be positioned so that, unless workers otherwise desire, no other workers appear within 0 to 40^{o} of any individual workers' field of vision.

26. Restraining devices should allow body movements so that eye-to-eye contact can be achieved.

27. Retractable or removable barriers should be placed between work stations.

28. People within common or "public" areas should not be exposed to people outside of the areas but should be able to tell when someone else is approaching or entering.

29. Variable intensity area lighting is recommended as a mechanism to breakup large areas.

30. Windows are highly desirable because they provide an alternative to looking at another person.

31. Pictures and other graphic designs are recommended since they offer useful alternatives to intense social interaction.

32. We recommend against visual surveillance in the crew quarters or hygiene maintenance facilities and have reservations regarding uninterrupted visual surveillance in the work and common areas.

33. Comunication between the crew and mission control should be accomplished with full duplex audio-visual systems.

34. Individual crew members should have the opportunity for private, full duplex audio-visual communication with family and friends.

Auditory privacy exists to the extent that one astronaut is not distracted or disturbed by another astronaut's speech, and to the extent that two or more people are free to communicate without being overheard by "outside" parties. Auditory privacy is achieved by (1) a general reduction in all sounds, including sounds within the frequency ranges that typify human vocalizations; (2) a selective reduction of sounds within the frequency ranges that typify vocalizations; and (3) masking vocalizations by means of increasing the intensity of non-human sounds relative to the intensity of human sounds.

Two of the most common methods for achieving noise reduction - increasing the mass of the wall or barrier between two areas and damping of sound by means of transmitting it outside of the habitat - are either difficult or impossible to apply in orbit. Viable options include friction (conversion to heat) or material dampening, in which the energy responsible for the sound is absorbed by walls or other materials. Optimal damping can be achieved by using loosely-joined layers of highly viscoelastic materials (VEMs) such as rubbers and plastics.

35. High degrees of auditory privacy are required in individual crew compartments and in personal hygiene areas.

36. In order to meet or exceed established design requirements, special materials and constructions must be examined and tested.

37. Glass fiber and magnesium or cobalt alloys should be considered for structural members.

38. High loss factor VEMs such as neoprene/silicone rubber composites should be considered for insulating wiring and piping.

39. Internal constructions should involve point-connected multiple layers of VEMs and absorbent foams.

40. Glass fiber and ferromagnetic magnesium alloy materials are desirable for panels.

41. Sound reduction in areas where visual contact remains desirable should be attempted through the use of transparent partitions of glass fiber and vinyl construction.

42. Wherever possible, exposed surfaces should be covered by noise-reduction material.

43. Crew quarters' doors should be staggered, to retard sound transmission from one private room to another.

44. All doors, hatches, and partitions should be sealable through magnetic or friction seals of rubberized construction

45. In areas that are characterized by relatively loud, continuous, or repetitive sounds, negative sound systems should be considered.

46. In areas where there is continuous noise in excess of 55 dBA, personal communications or "intercom" systems will be required.

47. Background noise should not be completely eliminated.

48. Personal cassette recorders or comparable systems provide an opportunity to mentally "tune out" other people.

49. Astronauts within private rooms should have the opportunity to monitor Space Station and Space Station/Earth communications.

50. Intercom systems should make it possible to attract the attention of specific individuals without disturbing others.

Olfactory privacy exists to the extent that an astronaut is able to complete his or her duties without being distracted or annoyed by odors. The detection of other people's odors may be interpreted as crowding, and lingering body odors serve as "contaminants" or reminders of an area's previous users and thereby render it less private.

51. Holding interior volume constant, waste management facilities require 12-15 air changes per occupant per hour. For a single user facility of approximately 100 ft^3, this implies movement of 20-25 ft^3/min.

52. Individual crew quarters will require approximately 15 ft^3/min. of air flow.

53. Work stations will require an air flow of 15ft^3/min. per person.

54. General meeting and other "public" areas should have fresh air flows of 25-40 ft^3/min. per person.

55. A three part air filtration system is recommended. The first part is electrostatic particulate removal, the second part is chemical filtration or dry scrubbing, and the third part is ultraviolet irradiation.

56. Exposed surfaces must be cleanable to eliminate residual contaminants.

57. Personal hygiene facilities should make it possible for each astronaut to wash on an ad-lib basis and undertake full body cleaning at least twice a week.

58. Provisions should be made for fresh changes of clothes at least twice a week.

Architectural and design interventions are not the only approaches to accommodating astronauts' privacy needs. Certain selection and trainining procedures and the development of appropriate social norms can help astronauts achieve desired levels of privacy.

59. Do not select individuals with unusual personal space requirements.

60. Compose crews in such a way that different crew members' needs are compatible.

61. Training in interpersonal relations and relaxation techniques will help reduce individual privacy requirements.

62. Steps should be taken to encourage the establishment of group norms regarding the use of different areas.

63. The scheduling of "alone time" removes the onus of temporarily retreating from the group.

Space Station Privacy Guidelines

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INTRODUCTION

People within all studied cultures attempt to regulate the degree of contact that they have with one another, although the nature, extent and expression of these attempts vary from culture to culture (Altman, 1975; Baldassare, 1978; Baldassare & Feller, 1975; Hall, 1959, 1966; Raybeck, 1987). Under some conditions, people attempt to expand the degree of contact that they have with one another, and under other conditions, they attempt to reduce interpersonal contact or keep it to a minimum. In spaceflight and analogous environments which require prolonged close confinement, providing inhabitants with the means to decrease social contact is the greater problem. As noted in *Man-Systems Integration Standards* (NASA, 1987), separation from others is in the interests of personal comfort and performance efficiency. The present paper offers Space Station guidelines for minimizing undesirable social intrusion.

Definition and Dimensions of Privacy

Privacy exists to the extent that people can control the amount of social contact that they have with one another. This contact occurs through four sensory modalities: vision, hearing, touch, and olfaction or smell. From an architectural and engineering standpoint, privacy is assured to the extent that an environment's occupants can regulate the extent to which they sense one another along these dimensions. For example, visual and acoustic privacy are promoted by walls and doors which cutoff sights and sounds; physical privacy through the distribution of people in physical space; and olfactory privacy through sanitation and air filtration systems which minimize the contamination of areas by personal odors.

Functions of Privacy

Restricting interpersonal contact serves a number of important psychological and social functions (Altman 1973, 1975; Bossley, 1976; Harrison, Sommer, Struthers & Hoyt, 1986; Marshall, 1974; NASA, 1987; Nixon, 1986; Raybeck, 1987). First, privacy helps people focus on scientific and other tasks that require or benefit from a high degree of concentration. Thus, minimizing contact with others can increase the efficiency and accuracy of individual workers. On the Space Station, there will be many scientific and other tasks which are best performed free of the potential distractions imposed by other people.

Second, the presence of other people increases physiological activation which initially energizes the organism (Zajonc, 1965) but which ultimately produces wear and tear on the organism. The freedom to remove oneself physically or psychologically from other people provides the opportunity to reduce stress and benefit from "rest and recuperation."

Privacy is also important for self-management. The opportunity to withdraw from others helps people adjust the images that they project, and hence regulate the relationships that they have with one another. Reducing one's accessibility to other people decreases the chances that socially devalued behaviors (for example, signs of personal weakness or antagonism towards another person) will create interpersonal conflicts. People require opportunities to "get off stage," thereby reducing the need for self-monitoring and censorship and alleviating worries about other people's perceptions and reactions (Archea, 1977; Bossley, 1976; Edney, 1976; Foddy & Finighan, 1980; Raybeck, 1987).

Fourth, privacy is required for limited and protected communication, that is, for two or more astronauts to converse without having to take the potential reactions of other astronauts or the entire crew into account (Connors, Harrison & Akins, 1985; Nixon, 1986; Raybeck, 1987). Simple examples include superior-subordinate interactions where the superior provides the subordinate with critical feedback, where the subordinate presents potentially threatening information to the superior, and where equals seek to resolve personal conflicts. In space as elsewhere, subgroups of astronauts are likely to have needs for private conversations with one another, and individual astronauts or subgroups of astronauts may want to talk privately with specific individuals on Earth.

Privacy and Crowding

Privacy provides protection against the potentially deleterious effects of crowding. High density living conditions or close physical proximity often contribute to, but do not always result in, the psychological experience of crowding (Altman, 1975; Dean, Pugh, & Gunderson, 1975, 1978; Epstein, 1981; Raybeck, 1987; Stokols, 1972; Stokols, Rall, Pinner & Schopler, 1973). Whether or not a given level of density or proximity will give rise to the psychological experience of crowding depends on perceptual and judgmental factors and the failure of interpersonal distancing tactics intended to reduce the perception of crowding. These tactics include the use of space and architecture, flight (turning away from an intruder or mentally tuning that intruder out), fight (behaviors which discourage intrusion on the other person's part), and the invocation of formal or informal rules (social norms) that prescribe acceptable social distances.

Persistent crowding may result in a number of potentially adverse effects. These include psychophysiological effects, such as increased heart rate, heightened blood pressure, and other indicators of stress (D'Atri, 1975; Epstein, Woolfolk & Lehrer, 1981; Evans, 1979; Greenberg & Firestone, 1977; Paulus, McCain & Cox, 1978); psychological effects, including tension, anxiety, negative emotions, and increased susceptibility to illness and accidents (Dean, Pugh, & Gunderson, 1975; Epstein, Woolfolk & Lehrer, 1981; Paulus, McCain & Cox, 1978; Webb, 1978); and social effects, including negative interpersonal attitudes and both overt and covert forms of social withdrawal (Altman, 1973; Baum & Greenberg, 1975; Bossley, 1976; Greenberg & Firestone, 1977; Evans, 1979; Sundstrom & Altman, 1976; Vinsel, Brown, Altman & Foss, 1980). Crowding has also been associated with performance decrements, such as increased memory deficit, error, and decreased ability to develop appropriate performance strategies (Karlin, Rosen & Epstein, 1979; Langer & Saegert, 1978; Paulus, Annis, Seta, Schkade & Mathews, 1976; Saegert, Mackintosh & West, 1975).

Case histories ranging from those of the earliest polar explorers to the spacefarers of today suggest that spaceflight and spaceflight-analagous environments can at once intensify people's needs for solitude and make solitude difficult to achieve (Altman, 1973; Bluth 1981, 1982; Boeing, 1983a, 1983b; Douglas, 1986). For example, Skylab astronauts have commented on needs to be alone, and have expressed desires for private sleeping quarters and locations to store belongings (Bluth, 1981). Observations of Salyut crews suggest that rather than adapting to crowded conditions over time, the need for cosmonauts to restrict social contact

actually increases (Boeing, 1983a). High density living conditions may be the cause of other problems, such as complaints about other people's poor personal hygiene (NASA, 1987; Stuster, 1986). Reviews of the psychological and social dimensions of spaceflight and spaceflight analagous environments suggest that privacy issues are likely to gain in importance and complexity as a function of increasing crew size, increasing heterogeneity of crew composition, and increasing flight duration (Clearwater, 1985; Connors, Harrison & Akins, 1985; NASA, 1987). The problem is one of engineering the environment so that astronauts can apply interpersonal distancing tactics to control exposure (or the extent to which they are distracted by and forced to attend to other people) and access (or the extent to which they are denied relief from the scrutiny of their fellow astronauts and monitors on Earth). Providing astronauts with control over exposure and access is a recognized concern in the area of spacecraft design (NASA, 1987) and is expected to promote safety, performance, and a high quality of life.

Optimal Privacy: A Matter of Degree

Optimal levels of privacy depend upon such factors as location, activity, and personal preferences as determined in part by gender, culture, and other variables. For example, a high degree of privacy is required for individual cabins and for personal hygiene facilities (Nixon, 1986; NASA, 1987; Stuster, 1986). On the other hand, design features should promote social contact in areas such as ward rooms, where socializing is a normal activity (Nixon, 1986; NASA, 1987). The degree of privacy required for a working area depends upon such considerations as the degrees of concentration and interpersonal coordination that are desirable.

Plans to minimize social intrusion have to be weighed against other considerations. For example, whereas decreased illumination may reduce the perceptual salience of an area's occupants, it may also make it difficult or impossible to perform certain tasks. Also, the goals of privacy and good communication may conflict. People communicate verbally through the spoken language and nonverbally through facial expressions, postures, gestures, and touch. Architectural and other elements which retard or block verbal or nonverbal messages by definition reduce communication.

Privacy and Space Station Design

Two conditions complicate the task of designing the Space Station in such a way that interpersonal intrusions will be kept to a minimum. These are the need to accommodate heterogeneous crews, and spaceflight environment engineering constraints.

Accommodating Heterogeneous Crews. Whereas the earliest spacecrews tended to be highly homogeneous in terms of age, sex, ethnicity, and professional background, more recent and anticipated crews are more heterogeneous in composition. Current plans call for a Space Station capable of accommodating crews of both sexes and drawn from many different nations. This has two implications. The first is that the Space Station must accommodate people of a wide range of sizes. Thus, activity envelopes (the amount of space provided for a person to perform a particular task) must be large enough for all but the largest individuals (top 5% of American males). The second implication is that since privacy needs vary as a function of such variables as gender and culture (Altman, 1975; Hall, 1959, 1965; Raybeck,1987), the Space Station must accommodate people who are very different in terms of their privacy needs. A recent review by Raybeck (1987) illustrates this variety:

1. North American women are more tolerant of close physical proximity than are men. The same social density levels that men describe as "crowded" women describe as "cozy."

2. North Americans and Northern Europeans require greater physical distances from other people than do people from Mediterranean, Asian, and Middle Eastern cultures.

3. Representatives of Middle Eastern cultures are less reliant on visual and auditory cutoffs (walls, doors, etc.) than are representatives of North American and Northern European cultures.

4. Members of Asian cultures tend to be very tolerant of close physical proximity. They are less reliant on visual and auditory cutoffs for achieving psychological distances from one another than upon meditation and other psychological mechanisms.

5. In some cultures, there are strong pressures against seeking solitude. A person who seeks to be by himself or herself may be seen as disinterested in the collective welfare of the group or as seeking the opportunity to engage in some form of deviant behavior.

The variability associated with locations, tasks, cultural differences, and individual differences suggests designing space habitats in such a way as to accommodate a wide variety of privacy needs (NASA, 1987; Nixon, 1986; Stuster, 1986). This can be achieved by developing a number of areas that differ in terms of the extent to which they provide privacy; by making areas definable and redefinable to support solitary, small group, and entire crew activities; and by providing astronauts with training and other forms of assistance so that they can use other tactics to regulate their distance from one another. A sense of control *per se* can provide major benefits for an environment's occupants.

As Raybeck (1987, pp. 12-13) points out:

> "A large number of psychological studies have found that people respond better to challenging circumstances when they perceive that their actions can influence and even control the situations in which they find themselves. One of the major researchers into perceived control, Sherrod (1974) placed subjects in a crowded environment and provided them with access to a button which, if pressed, could remove them from their crowded circumstance. Nearly all subjects did not use the button, but its presence significantly reduced the negative reactions to the crowded environment. In a later study of aversive environments, Sherrod et al. (1977) found that the willingness of subjects to persist in a task while exposed to a noisy environment increased in direct proportion to the degree of their perceived control over the noise. Environments that have been designed to permit users a sense of control have been found to be less stressful than those where occupants perceived themselves to be unable to influence their surroundings (Zimrung, 1981). These studies and others like them strongly support the importance of perceived control as a mediator of stress in crowded environments ..."

Space Station Design Constraints. Normally, on Earth, devising facilities that promote the regulation of social intrusion is neither challenging nor expensive. For example, an architect planning a new office building can allocate separate areas for group and solitary work, freely locate walls to guarantee visual privacy , and increase the mass of walls in order to increase auditory privacy. He or she can specify heating and cooling systems with high rates of air exchange and excellent filtration systems, and in most cases the problem of two or more occupants literally bumping into one another in the course of performing a task does not merit serious consideration. In spaceflight environments, on the other hand, there are certain constraints which make privacy a very difficult problem.

Limited interior volume. All privacy elements must be engineered within the constraints of the Space Station's limited interior volume. These constraints include (1) the physical dimensions of the module, (2) the amount of space absorbed by life support and work equipment, (3) the amount of space that must be devoted to free passage. Multipurpose space can help overcome some of the problems associated with limited interior volumes (NASA, 1987).

Limited weight. Stringent weight constraints limit the number of interior barriers and their mass. This makes it difficult to control visual and auditory access and complicates the development of first class sanitation and ventilation systems.

Semi-closed life support systems. The need to recycle water and air complicates the development of sanitation systems which promote high levels of personal hygiene and ventilation systems which effectively minimize unpleasant odors.

Flight qualified materials. Design options are also reduced by the need to use flight-qualified materials. All design specifications must involve materials which are not only lightweight but which do not vent noxious gasses, are fire retardant, and are easy to clean. These restrictions mean that many inexpensive and normally suitable materials must be eliminated from consideration.

Microgravity. Three dimensional locomotion complicates the task of providing visual cut-offs. For example, partitions that on Earth would be just above normal eye height may prove ineffective because aboard the Space Station people can assume an infinite number of positions relative to the Space Station's "floor."

External environment. On Earth, sound can be conducted out of a habitat and either dissipated in the atmosphere or absorbed by the ground. Orbiting space habitats are not surrounded by high density atmospheres and are not anchored to large masses such as Earth. This means that within the Space Station sound remains until it is internally dissipated.

Despite such complexities, there remains considerable latitude for accommodating people's privacy needs in space. As Harrison, Sommer, Struthers and Hoyt (1986, p. 33) have noted:

> "It does not require large areas and a multitude of walls and doors to accommodate an array of [privacy] needs. The careful planning of "hard" architectural features, the use of light-weight or "soft" features (screens, movable partitions, and so forth); the availability of small personal items that can be used to stake out temporary territories; the creative use of decor variables such as color and light; and the recognition of possibilities in such areas as personnel selection, crew training, and social organization can fullfill a wide range of [privacy requirements] despite the Space Station's volumetric limitations."

Guide to Privacy Issues and Recommendations

The following four sections of the report address, in turn, locational (proxemic), visual, auditory, and olfactory privacy. Within each of these sections we consider (1) a statement of the problem, (2) general solutions, and (3) specific recommendations. Although we will consider each form of privacy sequentially, recommendations may apply to more than one form. For example, walls which prevent visual intrusion may prevent speech intrusion as well. We will conclude with a brief consideration of how selection, training, and other mechanisms which have little or no impact on actual Space Station design may help Space Station occupants to achieve privacy.

In all cases empirical testing is necessary to determine the actual effectiveness of the proposed recommendations. Tests involving high-fidelity mock ups and realistic tasks are strongly recommended. We also urge continuous post-occupancy behavioral evaluation to refine the privacy guidelines over successive generations of space habitats.

LOCATIONAL PRIVACY

Locational privacy refers to the control of social intrusion through regulating the distribution of individuals within physical space. For purposes of the present discussion, we offer a distinction between area privacy, which involves the physical separation of areas (for example, sleeping, working, and recreational areas), and proxemics, which involves regulating the spacing of people within a given area.

Individuals or groups that are located physically apart from one another have high locational privacy, while those that are nearby one another have low locational privacy. As the distance between two or more people increases, social intrusion decreases. First lost is the ability to physically touch the other person. As distance further increases, the other person loses prominence as a stimulus, and eventually becomes a nonentity. Scents can no longer be detected. Fine and then coarse gradations of facial expression can no longer be distinguished, and the other person becomes increasingly difficult to hear and understand. Of course, the privacy afforded by sheer physical distance can be augmented by walls, doors, and other visual and auditory cut-offs.

Statement of the Problem

There are two major sets of issues relating to locational privacy. The first set of issues, those centering on area privacy, require designing the Space Station in such a way that activity areas afford appropriate degrees of privacy. The second set of issues, those centering on proxemics, requires arrangements such that within a given area, individual users can at once achieve appropriate spacing relative to the work that they are trying to perform and to other area inhabitants.

Area Privacy. To support a range of human activities, the Space Station will have to include a range of locations which afford varying degrees of privacy. The *NASA Manned Systems Integration Standards* (NASA, 1987), drawing on a study conducted by McDonnell Douglas for the NASA/Ames Habitability Group, acknowledges the need to satisfy the varied privacy requirements of both individuals and groups. In terms of decreasing privacy requirements, activities are ordered as follows:

Rank	***Individual***	***Group***
1	Private Recreation	
2	Sleep	
3	Full Body Cleansing	
4	Personal Hygiene	
5	Urination/Defecation	
6		Small Group Recreation
7	Dress/Undress	
8	Medical Care	
9	Hand/Face Cleansing	
10		Exercise
11		Meetings/Teleconferences
12	Clothing Maintenance	
13	Life Sciences Experiment	
14		Eating
15		General Housekeeping
16	Meal Clean Up	
17	Materials Processing Experiment	
18	Payload Support	
19	Logistics, Resupply	
20		Meal Prep
21	Planning, Schedule	
22	Training	
23		Pre-Post EVA
24	ORU Maintenance	
25		IVA support of EVA
26		Prox Ops
27	Subsystem Monitoring	

Proxemics Proxemics refers to the crew member's ability to adjust his or her physical location to other persons or equipment within an area. There are two relevant strands of inquiry. The first, ergonomics, is largely concerned with optimizing interfaces between technology and the human operator (Sanders & McCormack, 1987; Clark & Corlett, 1984). An essential part of this optimization is achieving a good match between the physical capacities of the operator and the location and arrangement of the equipment that is to be operated. The second theme is provided by social psychologists and sociologists who have been interested in spatial preferences and interpersonal distancing mechanisms (Baldassare, 1978; Hall, 1959, 1966; Raybeck, 1987; Sommer, 1969.) Both lines of thought remind us that people are not inert and stationary. Instead, each person has a sphere of physical and social influence which extends outwards from

his or her body, and the size and shape of this sphere of influence change over time.

From the social psychological literature comes the concepts of territories and personal space (Altman, 1973, 1975; Hall, 1959, 1966; Raybeck, 1987; Sommer, 1969). A territory refers to a spatial area that is accessible to socially specified users (Altman, 1975; Davis & Altman, 1976; Edney, 1978; Esser, 1976; Lavin, 1981). Territories are roughly akin to "turfs" and range in size from large geopolitical areas which are the province of large numbers of people (for example, a nation or a country) to small areas such as bedrooms and berths which are assigned to specific individuals. An important distinguishing feature of territories is that they are located as places and hence have clear geographical referents. Personal space has personal rather than geographic referents. Personal space has been described as an invisible zone, comparable to a shell or "bubble" which the individual carries around from place to place (Sommer, 1969).

People attempt to avoid violations of their territories and personal spaces. In the case of territories, people erect markers which indicate that the space is occupied. An example would be scattering belongings over the top of a table to discourage other potential users. Intrusions upon personal space are discouraged by social customs and by defensive behaviors on the individual's part (Altman, 1975; Evans & Howard, 1973; Hayduk, 1978, 1981, 1983; Pedersen & Shears, 1973; Sommer, 1969).

While ergonomics has had a long involvement with technology design and utilization, human territoriality and the use of personal space have only recently been addressed scientifically. One of the differences between the two fields is that ergonomics is largely based on highly objective measurements of physical dimension and movement. Conversely, interpersonal proxemics tends to be oriented towards subjective impressions and psychological variables of a less accessible nature.

General Solutions

One method of promoting locational privacy is designing compartments or rooms to yield the differing levels of privacy associated with different work, leisure, and self-maintenance activities. Another is to design interiors which at once allow inhabitants to perform all necessary tasks and to achieve the appropriate degree of social contact with other area inhabitants. This can be done without architectural barriers through the positioning of equipment and restraint devices.

Separation of Task Areas The functional relationship analysis (McDonnell Douglas, 1986) reinforces the view that specific areas within the Space Station should be geared to activities which are arranged along a privacy continuum. At one end of the continuum will be sleeping quarters and personal hygiene facilities which afford the highest possible degree of privacy. We join those who forcefully recommend individual sleeping compartments which can support reading, writing, and other individual recreational activities (NASA, 1987; Nixon, 1986; Stuster, 1986). At the other end of the continuum is the ward room, which is likely to be open to all comers. Although it will not be possible to offer all shades of privacy, it is essential to provide at least some areas which afford intermediate degrees of privacy (NASA, 1987, Nixon, 1986; Stuster, 1986). In particular, Nixon has provided strong justification for such semi-private areas (Nixon, 1986, pp. 87-88). Such areas are expected to satisfy social and emotional needs and ease the resolution of interpersonal conflicts:

> Currently, there is no provision for including a semi-private /semi-communal facility on the Space Station. Individual privacy will be obtained by crewmembers spending time in their own Sleeping Compartments. In reality, the nature of private compared to communal accommodation is more complex and demanding... Station Specialists will invariably be U.S. citizens with military aviation backgrounds, while Mission and Payload specialists will be drawn from a variety of scientific, engineering, and cultural backgrounds. Many nations, many organizations, and many industries will be represented. Unlike astronauts with military backgrounds, it is probable that Mission and Payload Specialists will have fairly limited training or experience in performing effectively over long periods of time under difficult conditions.
>
> Given this mix of backgrounds, experiences, and cultures, it is quite possible that psychological, physiological, or socio/cultural problems and tensions will arise during the course of a long crew tour, both in terms of how crewmembers feel about each other as well as how they feel about their surroundings. The space station can be designed to minimize such tensions which may otherwise be aggravated by the limited choice of habitable facilities available, where crewmembers wanting privacy may constantly seek the refuge of their private Sleeping Compartments at the expense of social contact or interchange with others. For these reasons, it is concluded that... a Library and Study Facility for two or three

crewmembers to use occasionally will be an essential ingredient in helping to alleviate any social tensions which may arise if the only off-duty choice is between a Wardroom and a private Sleeping Compartment.

Proxemics

There are two basic ways to establish proxemic privacy. The first is to ensure that astronauts have ample space to perform their tasks without physically interfering with one another. The second is to provide them with the means to regulate physical distances from one another.

A fundamental requirement for any activity is the accommodation of all necessary body movements. A crew member in his or her quarters must be able to perform the natural movements associated with changing clothing or other private activities such as reading or journal writing. Galley equipment must be accessible and easy to operate. For example, if an appliance handle has to be twisted for the appliance to be opened, sufficient clearance must be allowed for an individual to grasp that handle and twist it with enough force to open the appliance; simply assuring that the door has clearance to open is inadequate. Workers at VDU or other work stations must have enough clearance along all dimensions to type, handle tools, manipulate small equipment, and perform all other necessary tasks. In any and all situations where more than one individual can be expected to work simultaneously or cooperatively, enough physical space must be available for all individuals to fit into the area and do the work that needs to be done. For example, if two people are required to coordinate manipulation of a robot arm not only should required windows and controls be located so that both persons can see out the window and reach the controls, the area around the window must be large enough for both persons and all necessary movements.

The design constraints of user interfaces rely on anthropometric data specifying the relevant dimensions, or range of dimensions, to be found in the potential user pool (Singleton, 1982). Since it is impractical to design controls for every conceivable user, a range of physical dimensions are usually preferred. In space environments such as the Space Station, this range currently includes 5th percentile oriental female through 95th percentile American male. These population characteristics are widely available (Singleton, 1982; Kroemer, 1984) and provide the quantitative basis for many of our recommendations.

As Cushman (1984) points out, static anthropometric measurements of bodily dimensions are rarely sufficient to specify requirements of the users of equipment. Therefore, dynamic representations of activity envelopes (spatial representations of volumes and distances required for a given activity) in potential environments is required. Cushman also points out that, when the population of potential users of a piece of equipment changes, the anthropometric means change. A suggested solution is to use members of population extremes in dynamic representation methodologies to ensure that the equipment will work for all anticipated uses. A final point that Cushman emphasizes is that activity envelopes are often poorly estimated because testing procedures include unnatural restrictions on movement. In testing for the Space Station, gravity and the posture associated with gravity may constitute "unnatural restrictions." We recommend that a comprehensive series of STS flight experiments be carried out in order to accurately determine the full range of body movement envelopes associated with normal performance of prescribed activities for the 5th to the 95th percentile anthropometric range.

In situations where minimum requirements are to be specified (such as console width or corridor dimensions) the largest expected values are to be used. In the Space Station, these values are likely to be obtained by the largest persons who will be aboard --- 95th percentile American males. Conversely, maximum requirements (such as the maximum control distances from a restrained equipment operator) are to be based on the minimum expected values, those based on 5th percetile oriental females. Activity envelopes pertinent to the Space Station have been provided by Nixon (1986) and may be found within the *Man-Systems Integration Standards* (NASA, 1987).

Physical allowances are not enough. Cultural determinants of personal space and territoriality cannot be ignored in the design process. For example, sufficient space for two or more people to engage in a conversation requires more than enough space for the people to enter, interact, and then leave the area. Most non-intimate task-related interactions between two persons occur with an interpersonal distance of between 2.5 and 4 feet. Therefore, to support a comfortable conversation there should be at least three feet of separation between the area's occupants.

Appropriate and comfortable social interaction distances are well established for members of contemporary American culture (Altman & Vinsel, 1977). Less is known about the preferred interaction distances of American ethnic minorities. The limited information available on other

cultures suggests that compared to contemporary Americans, members of British and Northern European cultures prefer greater interpersonal distances for non-intimate interactions. Also, members of Mediterranean, Middle Eastern, and Asian cultures seem to require less interpersonal distance than do Americans (Raybeck, 1987). Preferred interpersonal distances may change in the absence of gravity, where a greater diversity of angular and spatial orientations can exist. Astronauts may develop a specialized subculture with its own rules regarding interaction distances. Astronaut preferences should be studied and integrated into the design criteria for proxemic privacy.

Territoriality and perceived control of access to one's own territory (physical or symbolic) is another important consideration. Again, cultural determinants are a major factor: the need for controlled territory is an important extension of the individual's self image (Sommer, 1969). Personal areas such as the individual crew quarters are an obvious case. As much as possible, individual occupants must have control over access to these areas. However, astronauts may also develop a sense of territoriality in work areas, particularly when more than one person is working on different tasks at the same work station at different times. To maintain privacy in these cases, there should be individual storage locations for task-related tools and materials. Individuals should be able to maintain control of access to work-related storage locations, although perhaps to a slightly lesser extent than to private quarters.

Recommendations

1. All spatial dimensions should be determined in accordance with the social as well as the physical requirements of the task. Specifications should be based on the extreme rather than average physical sizes of astronaut candidates engaged in dynamic definitions of activity envelopes for all relevant and important activities. Microgravity and cultural expectations should be taken into account.

2. Each astronaut should have an individual sleeping area (Helmreich et al., 1980; Stuster, 1986). Visual privacy should be complete within the sleeping areas and also within the personal hygiene maintenance facilities. All crew quarters should have doors which close completely and seal off unwanted light and sound. Once inside the quarters, the individual should not have to be concerned with any kind of visual surveillance. A small, one-way view glass or "fish eye" lense would allow occupants access to passers-by without exposing them to scrutiny in return. Recent research suggests that a small window in a crew quarter which provides a

view out to the corridor can enhance impressions of spaciousness inside the enclosure (Al Sahaf, 1987).

3. Personal crew quarters should be of sufficient size to permit the largest prospective crew member adequate space to engage in activities expected to occur in such quarters (Helmreich et al., 1980; Stuster, 1986). These include sleeping, changing clothes, reading, writing, and private work station operations. Minimum sleeper berth requirements should be 2.04 m in length by .86 m in width.

4. Crew quarters should be efficiently arranged for performing a variety of tasks and for expressing personal preferences with the minimum of intrusion on other people. They should include a pull-down desk for writing letters, keeping journals, and working on projects which require high levels of concentration. Private rooms should allow for control of heat and ventilation, as much as possible, and also for the control of light and sound without disturbing people in adjacent areas. Allowance should be made for "marking" a crew quarter by a personalized name plate on the door and the opportunity to display personal items within.

5. Inhabitants should have exclusive and final control over access to their individual crew quarters (except in cases of emergency).

6. Personal possessions are construed as extensions of the self and are also useful for marking territories. Allowance should be made for the storage of personal possessions in private quarters (Helmreich et al., 1980; Stuster, 1986).

7. Entrances to opposing individual sleeping quarters should be staggered or arranged at angles rather than perfectly aligned with one another so that entrances and exits can be accomplished without unexpected, direct confrontations with other people.

8. If possible, crew quarters should be large enough to accommodate two individuals for brief periods of time so that limited and protected communication can transpire.

9. Multiple personal hygienic facilities should be available (Stuster, 1986). These should be located as far away from work areas as possible. They should provide complete visual and auditory privacy and should be well ventilated. There should be one facility for each four astronauts (NASA, 1987).

10. There should also be an area (possibly a library and study area, as suggested by Nixon [1986]) which can accommodate two or more people comfortably. This area should screen occupants from visual and other forms of scrutiny and make it possible to hold private conversations.

11. Some area (possibly the galley) should be large enough to accommodate the entire crew at any one time. Eating and other activities which involve the entire crew can facilitate social interaction and promote group cohesion (Stuster, 1986).

12. Adequate clearance should be provided at all work stations. Based on a 95th percentile American male, shoulder clearances should be at least .660 m (.711 m for eating activity), not including clearance to ensure that physical intrusion of the crew member does not occur (estimated distance approximately .45-.75m). Restraints should be sufficiently user adjustable to permit distances of VDU workstations of .38 to .76 m. They should also be adjustable to promote communication with other crew members and allow freedom of movement. Minimum clearance from work station to far wall should be 2.03 m, to permit non-distracting passage of another crew member.

13. Work stations should be staggered to permit perpendicular and diagonal clearances of at least 2.03 m.

14. At each work station, storage areas should be provided for task-related materials and tools. At least one secure storage space should be provided for each crew member expected to use the work station on a regular basis.

15. Areas where face-to-face communication is expected should be at least 1.7 m in width, to permit effective interaction. Public access areas should be designed to give crew members access to the area in accordance with existing requirements for non-intrusive interpersonal distancing. (We suggest minimum distances of .30 to .45 m around each crew member.)

16. Movable panels and screens may be used to expand and contract work, living, and recreational spaces (Helmreich et al., 1980).

17. Movable or rearrangeable furnishings encourage the redefinition of areas to include greater or lesser numbers of people.

18. The allocation of personal or quasipersonal territories (such as work material storage areas) should be based on needs as defined by work assignments, and should not be distributed or revoked as rewards or punishments. These territories should be of equivalent size whenever possible. One crew member's personal territories should not intrude, via any sensory modality, into any other crew member's personal territories, and should remain distinct from all other territories. Each person's storage areas should be distinctively marked.

19. As much as possible, all pieces of equipment, restraints, and aids should be adjustable and relocatable to accommodate anthropometric variations and personal preferences. The positioning of restraints is particularly important for interpersonal access and exposure.

20. Positioning devices (grab bars, restraints, "seats," and other anchors) should make it possible for astronauts to move normally without colliding with one another.

21. Positioning devices should encourage interaction on the same horizontal visual plane; that is, during a conversation, one person should not be forced to "look up" to another.

VISUAL PRIVACY

From the individual astronaut's point of view, visual privacy is achieved to the extent that it is possible to control one's visibility to other astronauts, and to the extent that it is possible to restrict other astronauts from entering into one's own field of view. Visual privacy coincides with area privacy, providing that specific areas are architecturally delimited with opaque walls and doors. However, it is possible to influence visual privacy without resorting to these "hard" architectural features. Also, the degree of visual privacy depends upon surveillance and communication systems which allow other people to intrude irrespective of sheer physical distance and architectural barriers such as walls. Holding locational (area and proxemic) privacy constant, there remains a number of means to limit visual intrusion.

Statement of the Problem

Providing astronauts with the means to control visual privacy should help them perform at maximum efficiency and also promote positive interpersonal relationships and psychological well being. Lack of visual privacy, in general, will lead to stress responses, such as higher blood pressure, increased heart rate, and expressions of frustration and hostility (Evans, 1979). Energy expended to reduce this stress diminishes the amount of energy left in the system, which in turn reduces the quality of performance, especially performance on complex tasks (McNeal & Bluth, 1981). Lack of visual privacy can also be embarrassing, for example, when a person is engaged in personal hygiene tasks.

Visual surveillance consistently induces stress responses (Greenberg & Firestone, 1977), and visual surveillance by superiors correlates negatively with supervisees' job satisfaction (Sundstrom et al., 1982). The impact on the crew of relentless surveillance by ground control has been a persistent concern (Berry, 1973; Connors et al., 1986).

General Solutions

Visual privacy can be increased by (1) the use of permanent or temporary architectural barriers; (2) the maximization of perceived (as compared to actual) space, which reduces feelings of crowding and increases feelings of privacy ; (3) variations in physical orientation vis-a-vis other area inhabitants; (4) the availability of nonsocial stimuli

or "distractors"; (5) the design of surveillance devices, and (6) variations in illumination.

Walls and Partitions The most obvious but perhaps least economical means for minimizing social intrusion is through the use of walls, partitions, doors, and other barriers which partially or fully obscure individuals' views of each other. Because of weight and space constraints, these architectural features will have to be used sparingly within the Space Station. As noted in the preceding section, architectural barriers can be used to help set-off different areas such as individual sleeping compartments. Here we note that walls and partitions can also be used to achieve privacy within an area. The use of partitions or barriers that can be relocated or repositioned would have the advantage that the interior layout of the Space Station can be modified as a result of trial and error testing or in anticipation of changing crew needs.

Maximization of Perceived Space. Environmental features which enhance perceived space tend to reduce perceptions of crowding and thereby increase impressions of privacy. When exterior dimensions are fixed, the maximization of interior space relies on design features that contribute to an atmosphere of spaciousness (Raybeck, 1987). Interiors that feature light, pale, or desaturated colors are likely to be perceived as more spacious than are areas that feature dark colors (Mandel, Baron & Fisher, 1980; NASA, 1987; Raybeck, 1987; Schiffenbauer, Brown, Perry, Shulak & Zanola, 1977). Among the many advantages of windows is that they tend to "open up" an environment and increase its perceived size (Al-Sahhaf, 1987; Haines, 1987). As Nixon notes, "A horizontal interior architectural configuration is more effective than a vertical configuration at accentuating and stimulating crew perception of internal spaciousness and perspective due to the absence of visually-restrictive intermediate floors present in a vertical configuration" (Nixon, 1986, p. ii). Irregularly shaped rooms are perceived to have more volume than compact or regularly shaped rooms of equal volume (NASA, 1987; Wise, 1987).

Angles of Interpersonal Orientation. Within an area, occupants' angles of orientation relative to one another contribute to interpersonal distance. Maximum exposure and access result from face-to-face orientations while reduced exposure and access result from positioning occupants at angles such that they do not enter each others' fields of view. Some tasks, which involve a high degree of interpersonal coordination, require that workers be highly visible to one another. This makes it possible for people to communicate nonverbally. For example, Koneya (1977) has found that communication between co-workers is most

successful if the co-workers are directly in front of one another. If workers must shift their gaze more than 40^{o} to either side of their lines of sight to see each others' faces, nonverbal communication is impaired, and if they must shift their gaze more than 90^{o}, visual communication dwindles to nothing.

Distractors. Visual distractors consist of features such as windows, works of art, and visual patterns which provide nonsocial visual fixation points. Focusing gaze on distractors makes it possible to avoid intense social interaction, and, to some extent, mentally tune other people out.

Surveillance Systems. The advantages of keeping space crews under continuous video surveillance must be weighed against the stress and dissatisfaction that relentless surveillance may cause. According to one expert, each environment requires some "free places" where surveillance is removed or reduced (Bossley, 1976). Congruent with this is Berry's (1973) suggestion that ground control keep only one section of the spacecraft under surveillance, thereby allowing people in other sections to be free of surveillance at least part of the time. Other possibilities include the use of two-way surveillance systems which reduce the stresses associated with access without exposure (being seen by ground control personnel without being able to see ground control personnel in return) and making it possible for the astronauts to shut off video cameras and microphones.

Illumination. There are several ways in which variations in lighting can affect visual privacy. A person who is able to reduce light in a given area can decrease social accessibility. Variations in illumination can be used to demarcate or "set off" an individual or group of individuals from other individuals in the same or adjacent areas. If one area is characterized by low illumination and another by high illumination, the person in the low illumination area is relatively inaccessible to the person in the high illumination area, whereas the person in the high illumination area is visually accessible to the person in the low illumination area. Thus, providing Space Station inhabitants with the opportunity to turn lights on and off and to vary their intensity provides them with a means to regulate visual exposure and access.

Attempts to control privacy through illumination must proceed within constraints imposed by the need to provide excellent visibility (NASA, 1987). Considerations include (a) proper illumination levels as determined by lamp power, lamp location, and surface reflectance; (b) proper figure-ground contrast with minimum glare; and (c) ensuring that

the illumination levels within two adjacent areas are such that workers moving between them do not have difficulty trying to adapt (NASA, 1987).

Lamp color can have important psychological and social effects. Lamp color depends on illumination level and the distortion or exaggeration of various segments of its emitted visual spectrum. Values are based on radiation spectra of idealized bodies with energies corresponding to a specific temperature (in degrees Kelvin) and are often referred to as "color temperature" values (Boud, 1973). Lower color temperatures have higher elements of yellow and red. The distribution of sunlight on the Earth's surface is fairly constant in the range of 4500K-6000K. (The range 5000-6000K shows a nearly flat, that is white, distribution; there is a slight exaggeration of orange/red at 5000K and a slighter exaggeration of green at 6000K). Boud suggests that humans have come to associate lower levels of illumination and redder or "warmer" sources of light with nighttime and social activities, perhaps due to associations of low illumination levels with nighttime and red colors with sunsets (Boud, 1973). Higher color temperatures and bluer sources are associated with higher activity levels (Boud, 1973). Everyday descriptions of red sources of light as "warm" and blue sources of light as "cool" are ironic because the actual color temperatures of red light sources run cooler than do the actual color temperatures of blue light sources.

Fluorescent lights show tremendous advantages over incandescent lights in nearly all relevant areas. Fluorescents are higher and more efficient in light output per watt of power input and the heat that is generated is convective or conductive rather than radiant so that the light remains cooler. Further, fluorescents have a wider color temperature range, are less sensitive to vibration, and have a longer life (Boud, 1973). Fluorescents provide for more accurate color perception; the range of color temperatures made avaliable for incandescent lights (2500-2800K) is too shifted toward the red section of the spectrum (Sanders & McCormick, 1987). The wide range of color temperatures available in fluorescent lights (3000-6500K) makes it possible to mimic earthbound illumination conditions. Following Boud's hypothesis, Clark and Corlett (1984) suggest that "warm white" (3000K) light is preferable for low lighting areas, and wide-spectrum or "daylight" (4500-5500K) for high lighting areas.

Recommendations

22. Since light areas appear less crowded than do dark areas (Mandel et al., 1980; Schiffenbauer et al., 1978) we recommend the use of relatively light, pale, or desaturated colors on interior walls .

23. Horizontal layouts are preferable to vertical layouts since they produce areas of greater perceived spaciousness (Nixon, 1986).

24. Irregular interior shapes are recommended because they appear more spacious than do interiors which are arranged in common and simple geometric patterns (Wise, 1987).

25. We assume that some of the work performed aboard Space Station will require the highest degree of concentration. Therefore, within work areas, visual privacy will be important. To achieve this, we recommend that each individual worker station be positioned so that, unless workers otherwise desire, no other workers appear within 0 to 40° of any individual worker's field of vision.

26. In some cases, workers will benefit from clear, unobstructed views of one another. Thus, restraining devices should allow such body movement such that eye-to-eye contact can be achieved.

27 . In the interests of concentration, confidentiality, and security, retractable barriers should be placed between work stations. These barriers should be removeable, perhaps by sliding back into the console area. to open up the work space for joint tasks.

28. Visual privacy within the common or "public" areas, such as the galley or library, will be very hard to control. We recommend maximum access and minimum exposure. People within the area should have limited visual exposure to others outside the area, but the people within the area should be able to tell when someone else is approaching or entering. This might be accomplished by the use of opaque barriers surrounding the "sitting" area. Such areas can then provide a useful alternative to the cramped crew quarters for private conversations.

29. Area lighting is recommended as a mechanism to break-up large areas into public and semi-common areas. Within an area, variable intensity lighting helps occupants increase or decrease visual contact. Fluorescents are recommended for area lighting.

30. Windows are highly desirable (Al-Sahaf, 1987; Haines, 1987; Helmreich et al., 1980). Windows give us a region to look at when we want to change one set of visual stimuli for another, or when we want to avoid looking at another person. By providing distal fixation points, windows can

help reduce feelings of crowding on board. Because windows can provide useful sources of distraction from social stimuli, they serve important privacy as well as other functions. The privacy function of windows will be most pronounced in public or common areas such as the galley. Windows should be outfitted with blinds or shades, not only to protect against harmful glare and radiation but also for varying access to the outside.

31. We recommend including pictures and other graphic designs since they offer useful diversions which help regulate the intensity of social contact (Baum & Davis, 1976; Helmreich et al., 1980). In cramped environments, pictures which provide an illusion of depth and offer distal fixation points provide an advantage (Coss, Guse, & Clearwater, 1987). NASA pictures may serve an important symbolic function and reinforce mission values; pictures of Earth subjects may help reduce feelings of isolation from home. Complex stimuli can furthermore ameliorate boredom. Graphics can be printed on thin nylon sheets and changed at frequent intervals.

32. Remote video surveillance is a critical issue. On the basis of privacy considerations, we recommend against any visual surveillance in the crew quarters or hygiene maintenance facilities, and have reservations regarding uninterrupted visual surveillance in the work and common areas. At the very least, there should be areas where individuals or small groups of people can remove themselves from ongoing video surveillance.

33. Communication between crew and ground control or other external parties should be accomplished with full duplex audio-visual systems so that all parties have equal exposure and access during any information exchange.

34. Communication between crew members and family members should also be accomplished by means of two-way audio-visual systems. These systems must be arranged in such a way that the astronauts who are using them can do so free from surveillance by other astronauts. In addition, these systems should be secure in the sense that they are not subject to electronic eavesdropping.

AUDITORY PRIVACY

Auditory privacy exists to the extent that one person is not distracted or disturbed by another person's speech, and to the extent that two or more people who are engaging in a conversation are free to communicate without being overheard by a third party (Archea, 1977).

Statement of the Problem

Sound has many effects upon human performance (Loeb, 1986), and the problem of achieving auditory privacy is only one problem of sound management within the Space Station. There tends to be high levels of ambient sound within spaceflight environments, and there is the general problem of keeping sounds within comfortable limits. In a survey of 33 Shuttle astronauts. Wilshire (1984) found that more than half of those who responded noted that Shuttle sound levels interfered with speech, disturbed sleep, made it difficult to relax, and were a source of annoyance. Seventy-four percent of the respondents argued that there should be lower background noise on the Shuttle, and 93% felt that there should be lower noise within the Space Station.

The standard unit of sound pressure level is the decibel (dB). The reference value of 0 corresponds approximately to the minimum threshold of human hearing in the mid-range of audible frequencies. For reference, a busy office has a value of 50-60 dB; a bedroom in a rural community about 20dB; and the music at a rock concert often reaches the 100-110 dB range. Human conversational speech is usually around 65dB, and the ambient sound level reported to exist in the Space Shuttle mid-deck area during orbital operations varies between 55-60 dB. The difference in dB between two sounds is equal to the logarithm of the ratio between sound pressures, multiplied by 2. Thus, a sound with twice the pressure as another would have a value 6 dB higher. However, each 10 dB difference in sound pressure level relates to a factor of two in loudness.

Because perceived loudness is a function of the frequency (in Hertz, Hz), several sound rating techniques are currently in use. The most commonly used is the "A" weighted rating (or dBA). Since frequency is an important determinant of speech intelligibility, and equivalent sound levels at different frequencies are perceived to have different loudness, several authors (Sanders & McCormick, 1987; Parkin, Humphreys & Cowell,1979) have suggested using Noise Criterion (NC) or Preferred Noise Criterion (PNC) curves instead. These curves are based on equal perceived loudness, and thus are weighted differently in the critical range of speech

communication (200-6100Hz) than in other frequency ranges. However, the A-weighting function does account in a simple way for the frequency response of the auditory system and in fact is not that different from the PNC weighting. The dBA can be ascertained on every sound level meter and requires no special analysis.

Recommendations for noise levels which impose minimum restrictions while precluding adverse effects on hearing mechanisms or performance have been offered in the *Guidelines for Noise and Vibration Levels for the Space Station* prepared by the Committee on Hearing, Bioacoustics, and Biomechanics Commission on Behavioral and Social Sciences and Education (NRC, 1987). For our purposes, the pertinent recommendations from that report are as follows (NRC, 1987, pp. 1-2):

> A. Space station laboratory modules should have A-weighted sound levels not exceeding 55 dB (a noise criterion curve of approximately 50) and reverberation times not exceeding 1.0s. These values should permit 95 percent intelligibility for sentences under conditions of normal vocal effort with the talker and the listener visible to each other.
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> B. For sleeping areas, background A-weighted sound levels below 35 dB are preferred, while levels up to 40 dB are acceptable.

At the same time that it is important to control noise it is important to ensure good verbal communication (NRC, 1987). There must be appropriate signal/noise ratios with human speech comprising the signal and all else providing the noise. For three reasons, the minimal levels of speech intelligibility that are appropriate during "everyday" face-to-face communications may not be acceptable in the case of the Space Station. First, aboard Space Station, there will be astronauts for whom English is not the first language. Given low levels of speech intelligibility, it is more difficult for non-native speakers to understand a message than it is for native speakers. Second, the minimal levels that are acceptable for normal speech are not acceptable for synthesized speech, which tends to sound flat and unemotional and which is delivered in the absence of visual non-verbal cues. The National Research Council (1987) recommends the Speech-Transmission-Index (STI) for predicting the effects of background noise and reverberation on speech intelligibility:

> While several methods exist for predicting the separate effects of reverberation and background noise on intelligibility, the Speech-Transmission-Index developed recently by Houtgast and his associates (Houtgast and Steeneken, 1973, 1985;

Houtgast, Steeneken and Plomp, 1980) provides an integrated framework for predicting intelligibility under simultaneous conditions of reverberation and noise. At the design and planning stages, the STI method can be applied theoretically with certain assumptions. On the actual or model Space Station, the methods can be applied empirically and objectively...

The output of the method is a number ranging from 0 to 1, called the STI value, which is monotonically related to speech intelligibility. The suggested limits on noise ($N \leq 55$ dbA, approximately NC-50) and reverberation ($T \leq 1.0$ s) were selected to obtain STIs in the range of .45 to .60. These STIs will allow about 95 percent intelligibility of sentences... This level of intelligibility is a typical target value that allows reliable communication of normal conversation... Conversation of a highly technical nature may require STI values above the specified range. Visual speech reading of cues that result from seeing the face of the talker can provide the necessary increment. Specifically, speech reading cues from untrained observers are typically equivalent to a 3 to 6 dB improvement in signal-to-noise ratio... which translates to STI increments of about 0.1 to 0.2.

Auditory cut-offs are critical in sleeping areas, waste management and personal hygiene areas, and areas where astronauts seek to communicate selectively with a limited number of other crew members, or, by means of telecommunications systems, with one or more external parties.

General Solutions

Auditory privacy is achieved by mechanisms which provide auditory cut-offs of human speech, that is, make it difficult or impossible to perceive human vocalizations. There are three methods: (1) a general reduction in all sounds, including sounds within the frequency ranges that typify human vocializations; (2) a selective reduction of sounds within the frequency ranges that typify vocalizations; and (3) masking vocalizations by means of increasing the intensity of non-human sounds relative to the intensity of human sounds. Given that the Space Station is likely to be a "noisy" environment, options (1) and (2), which involve noise reduction, are generally preferable to (3) which could involve an increase in overall sound levels. Since sound levels in the Shuttle (and, given current methodologies, expected in the Space Station) are in the 55-60 dBA broadband range, we can expect additional noise reductions of up to 20-30

dBA required to meet criteria for lab modules, and 25-40 dBA to meet criteria for hab modules. Although low frequency noises will require less noise reduction, these noises will be more difficult to reduce, and are thus a more demanding engineering problem (Harris, 1979). This problem will be referred to as "vibration control," to distinguish it from noise reduction in the higher (> 100 Hz) ranges.

Space Station Construction and Sound Control Two of the most common methods for achieving noise or vibration reduction (for example, reducing the amount that is transmitted between two rooms) are either difficult or impossible to apply in spaceflight environments. The first of these is to increase the mass of the wall or barrier between the two rooms. Because, in space structures, weight must be kept to a minimum, simply increasing the weight of the wall is not a desirable alternative. The second major option is to dampen the sound by transmitting it outside of the habitat where it is either dissipated in the atmosphere or ground. This is unworkable because spaceflight environments do not have an external atmosphere and are not anchored to a major mass such as Earth. The remaining options for dissipating sound are friction (conversion to heat) or material damping, in which the energy responsible for the sound is absorbed by walls or other materials. The most promising option for controlling vibration (< 100 Hz) aboard the Space Station is the use of highly viscoelastic materials in walls. Noise reduction (> 100 Hz) can be accomplished by using sound absorbing facings and creating "fuzzy" environments (Harris, 1979).

Optimal damping can be achieved by using layers of highly viscoelastic materials (VEMs) such as rubbers and plastics which store and slowly dissipate energy. The best VEMs are those which absorb a large fraction of incident energy (sound waves or structural vibrations) and dissipate it internally rather than transmit it through the material. Several researchers (Beranek, 1971; Harris, 1979; Fader, 1981) suggest that the prudent use of flexible, multiple layers of different VEMs can significantly increase damping over those obtained by simple and rigid structures. However, it is extremely important that these layers be as loosely joined as possible (point fastening rather than surface fastening) to prevent structural resonance and energy transmission effects which can eliminate the advantages of the VEM.

Absorption in the vibrational range is best obtained by materials with high material loss factors or internal dampening coefficients: nonstructural materials with high loss factors are rubbers, especially silicone and neoprene rubbers (Fabris & Sommer, 1973). Ferromagnetic (Beranek, 1981) and glass-fiber (Bulis Crema, Barboni & Castellani, 1982)

materials have been found to have higher internal damping than other structural materials, and should be considered wherever possible. When point connected, materials are more free to deform, and thus are more able to dissipate rather than transmit energy within the structure. Composite structures are also more efficient dampers than homogeneous ones, due to energy losses involved in decoupling or moving from one material to another (Doelle, 1972; Lord, Gatley & Evenson,1980). An important consideration in the case of planning for the Space Station is that internal damping can decrease by up to 50% in a vacuum, partially because of outgassing of moisture (Bulis Crema et al., 1982; Tennyson, Morrison & Mabson, 1982). For this reason, space environments may be louder and "harder" (more energy transmissive and reflective) than expected on the basis of pretests on Earth. Thus, higher than nominal damping must be specified for spacecraft structures; materials calculated to be of marginal acceptability in Earth-based applications are likely to be inadequate in space.

Sound absorption in the acoustic range is often achieved by polymeric foam materials. These materials have a large inclusion of closed air cells, thus permitting increased energy loss by repeated decoupling between air and foam, as well as viscous losses. Unfortunately, many otherwise useful materials are precluded because they have flammability problems, and do little to absorb vibrations of less than 250 Hz (Miller & Montone, 1978; Papa, 1975). Both of these problems can be overcome through the judicious use of materials and applications of thin, impervious films which are not only flame-retardent but are of excellent cleanability. Applications of some films that are only 1 mil thick can significantly increase low-frequency absorption without harming acoustic-frequency behavior of the foam (Fabris & Sommer, 1973; Wilson, 1975). Polyimide foams are not considered a fire hazard due to their high ignition temperatures and low smoke generation (Wilson, 1975).

Additional sound reduction can be obtained through well-sealed enclosures, as well as sound-reducing partitions placed within the air space of the environment. In these cases, sound is prevented from being transmitted easily through the air from room to room or area to area. Rubberized or magnetic door seals should be considered for general use (Miller & Montone, 1978). Translucent or transparent glass-fiber curtains with vinyl backings or substrates combine lowered sound transmission with good flame-retardant behavior (Doelle, 1972; Miller & Montone, 1978; Papa, 1975).

Testing procedures in determining noise reduction performance of various materials and environments are very difficult and uncertain (Beranek, 1971). Specifically, it is of tremendous importance that materials be tested, whenever possible, in their final configurations and with as realistic a noise source as can be obtained. Thus, although materials can often be suggested, they should not be used in the final design without realistic tests in high-fidelity simulation conditions.

Masking Noises. In certain areas, broad band masking noises can minimize the effects of social intrusion. These include sources of white noise such as fans or possibly music (Boeing, 1983b). Masking noises have the additional advantage that they tend to decrease the annoyance value of intermittent sounds. Masking noises should either be limited to high privacy areas (sleeping quarters, personal waste management facilities, etc.) or delivered by means of headphones, so as not to interfere with task-oriented speech communication or increase the ambient sound level. Masking noises in individual quarters should be under the control of the quarters' inhabitants (NRC, 1987).

Negative Sound. Negative sound may be of use in areas that are characterized by relatively loud noises that are either continuous or highly repetitive. Negative sound generation systems, such as manufactured by the Bose corporation, generate sound waves which are the complement or mirror-image of the environmental sound wave, thereby neutralizing or cancelling the environmental sound.

Personal Communication Systems. The National Research Council Report points out that within environments having sound levels above 55 dB(A) inhabitants will require assistance for adequate speech communication.(NRC, 1987). These systems might consist of headsets with close, silica gel filled seals and either highly directional microphones or throat microphones designed to pickup maximum speech and minimum noise. Since such systems can amplify and distribute noise as well as speech signals to both intended and unintended listeners their use should be carefully controlled (NRC, 1987). Such systems should be wireless and may involve microwave or infrared transmissions. They will also be of use for communication between workers who are at different locations within the Space Station.

Recommendations

35. High degrees of auditory privacy are required in individual crew compartments and in personal hygiene areas.

36. In order to meet or exceed design requirements set forth by NASA (1987) and the NRC (1987), special materials and constructions must be examined and tested. All structures must pass relevant standards for flame retardancy, toxicity, and cleanability. Candidate constructions should be tested under realistic conditions, preferably in situations similar to the expected final configurations. For example, panel constructions should be tested in current Space Station orientations, using broadband acoustic measurements similar in spectrum to those expected on the Space Station.

37. Glass fiber and magnesium or cobalt alloys should be considered for use in structural members in all space environments. Qualifed materials should have loss factors of no less than .01 achievable in vacuum.

38. High loss factor VEMs such as neoprene/silicone rubber composites should be considered for insulating wiring and piping. Loss factors of .1 achievable in vacuum should be considered minimum standards for such VEMs; factors of .25 or higher are desirable. These compositions have already been shown to have space applications in insulation and spacesuit constructions (Fabris & Sommer, 1973).

39. Internal constructions should involve point-connected multiple layers of VEMs and absorbent foams.

40. Glass fiber and ferromagnetic magnesium alloy materials are considered desirable for panels. Large panels should be separated by 1" to 3" of low-density (1 lb/ft^3) polyimide foams. All facing surfaces should be laminated with no more than 1 mil silicone or mylar impervious film. These composite structures should be able to demonstrate sound absorption coefficients of no less than .30 in the range of 31.5 to 200 Hz, increasing to no less than .90 in the range 500 to 4000 Hz.

41. Sound reduction in areas where visual contact remains desirable should be attempted through the use of transparent partitions of glass fiber and vinyl construction. These partitions should be flexible and sealable, and reduce sound transmission by at least 5 dB.

42. Wherever possible, exposed surfaces should be covered by some type of noise reduction material capable of increasing sound and vibration absorption in the range 1 to 10000 Hz.

43. Crew quarters doors should be staggered, to retard sound transmission from one private room to another.

44. All doors, hatches, and partitions should be sealable through magnetic or friction seals of rubberized construction.

45. In areas that are characterized by relatively loud, continuous or repetitive sounds, negative sound generation systems should be considered.

46. In areas characterized by noise in excess of 55 dBA, personal communications or "intercom" systems will be required.

47. Background noise should not be completely eliminated. Some minimal level of continuous background noise would help minmize the distracting effects of talking and other intermittent noises. As noted in the NRC (1987) report, the intensity and duration of the masking noise should be under the control of the individual crew member.

48. Personal cassette recorders or other personal music systems provide an opportunity to auditorally tune other people out (Boeing, 1983b). Personal music systems offer advantages over public or group systems, including the opportunity to control volume and content. Control over content allows people to enjoy selections which other people dislike, and thus helps prevent programming conflicts. Used with headphones, these devices will not contribute appreciably to the overall noisiness of the environment.

49. Within private rooms, occupants should have the opportunity of monitoring Space Station and Space Station/Earth communications that are of a public nature. Communicators should be aware that the communication is being monitored.

50. Inflight paging or intercom systems should make it possible to attract the attention of specific individuals without disturbing others.

OLFACTORY PRIVACY

Olfactory privacy is available to the extent that an astronaut is able to complete his or her duties without being distracted or annoyed by odors. The detection of other people's odors may be interpreted as crowding (Stuster, 1986) and lingering body odors serve as "contaminants" or reminders of an area's previous users and thereby render it less private (Altman, 1975).

Statement of the Problem

The physiology and psychology of odor perception is not as well developed as the physiology and psychology of vision and audition, but olfaction may have a very important role in environmental and social awareness and interactions (Engen, 1982). Odor control must take into account health concerns, personal objections, and the intrusion of odors associated with one individual into the territory of another. With respect to health concerns, many toxic substances are odorous. These substances can often be detected far below those levels of concentration that are determined to pose a danger to health. If the odors associated with these substances are considered unpleasant by workers, dissatisfaction and reduced work performance can result. Negative reactions are also associated with some odorous materials which are not considered toxic. A primary example would be the nonlethal, but objectionable, qualities of isovaleric acid (a primary constituent of body or "dirty sweat sock" odor). Such odors must be controlled for preferential, rather than medical, reasons.

Although negative responses can be expected to unpleasant odors, one cannot assume that conditioning will occur with odors. Adaptation to an odor occurs fairly rapidly, and qualities of one odor can interact in complex ways with qualities of others (Engen, 1982). A further danger is that some toxic chemicals have odors which are commonly perceived as pleasant. Therefore, although the odors of many toxic substances can be detected long before they reach dangerous levels, humans are of limited ability to detect changes in levels or determine the presence of multiple odors.

While research involving the manipulation of human interactions through odor has been criticized on methodological grounds, there is a definite possibility that humans are sensitive to social and emotional responses mediated by pheromones, or odorous chemical messengers (Engen, 1982). The plasticity of human and primate behavior suggests that pheromones

will not control behavior to the extent that they do in other species such as moths. Nonetheless, womens odors change throughout the reproductive cycle and these changes may trigger responses on the part of other women (Engen, 1982). Sexual attraction and territorial behavior have been linked to the presence of androstenol, a substance primarily associated with men's urine and sweat (Engen, 1982). Reactions to various body odors are subjective and associated with specific individuals. It is therefore likely that, in humans as well as animals, individual identification can be based on odors. Since odors can also be associated with places that specific individuals have been, odors may possibly act as territorial markers in the human as well as in the animal realm (Altman, 1975).

Any set of specific recommendations to achieve olfactory privacy is necessarily limited. The nongeneralizable nature of odors requires the testing of specific substances and combinations under realistic conditions. Specific environmental variables (such as temperature and humidity) also must be examined in discussions of volatility and airborne concentrations of odorous molecules such as would be found in crew quarters and waste management facilities. Testing of filtration and purification systems will be essential. Examples of substances for testing include 3-Methylindole (a primary constituent of fecal odor) with a threshold of .05 ppm (parts per million); androstenone (male body odor), with a threshold of 4 ppb (parts per billion); butyric and isovaleric acids (found in sweat and urine, also constituents of body odor), with thresholds of .015 and .001-2.2 ppm (NRC, 1979). Also required is maintenance of carbon monoxide levels of below .1% (NRC, 1979). Astronaut diet will also affect the expected concentrations of odors produced by excreta (Summer, 1971). Astronaut subjective preferences, as well as objective data, are important to this aspect of privacy.

General Solutions

There are several methods commonly used for eliminating odorous substances from the air in public and industrial applications. The most salient are masking and decontamination.

Masking The use of pleasant scents which overpower unpleasant odors is not recommended for isolated and confined settings. Perfumes do not solve the problem of toxics in the air; rather, they may increase the concentration of undesirable substances. Also, the same scent that one group of people finds pleasant may be found unpleasant by another.

Decontamination Odor concentrations can be directly related to the flow rate of air in an enclosed space. The concentration formula is:

$$C_t = C_o * e^{-t/T}, T = V/w$$

where C_o is the initial concentration of the substance, t is time, V is the volume of the space, and w is air flow rate (e is the base of the natural logarithm scale = 2.718...). Examination of this equation shows that our ability to control odor concentration in an enclosed volume is directly related to our ability to move clean (odor-free) air through the space.

Lacking more specific data regarding the propagation properties of odors which can be expected in the Space Station, air flow rates can be estimated according to existing standards of air changes per hour to maintain fresh air in various types of spaces (Summer, 1971). Fresh air is considered to have a carbon monoxide (CO) level of less than .1%; and Summer's figures are based on volume of air required per person, as well as types of spaces (conference rooms, public toilets, private offices, and homes). Knowledge of the type of space can provide information regarding movement through the space, odors likely to be present, and the effects of these odors on tasks intrinsic to the space. These figures can be modified to maintain acceptable concentrations of all odors expected in the various areas of Space Station.

Electrostatic Ionization The simplest of the methods for air decontamination available in spaceflight environments is electrostatic ionization. This process is effective only on relatively "large" (.001 micron or greater) particles because only large particles are capable of acquiring static charges. Charged particles are then attracted to filter collectors of opposite charge. Although inexpensive and effective for removing airborn contaminants, electrostatics does not actually eliminate offending substances. Further, most odorous chemicals are composed of molecules smaller than the effective range of electrostatic collectors.

Dry Scrubbing Chemical filters or "dry scrubbing" purification methods (Summer, 1971; NRC, 1979) provide the simplest true means of odor elimination and air purification. In this process, contaminated air is passed over a chemical bed or substrate. Contaminants react with the chemical bed and are converted to compounds trapped in the bed. The air, which remains nonreactive (or, in some chemical reactions, is replenished with oxygen or nitrogen), passes back into circulation. Carbon beds are considered by far the best current filter material as long as it is possible

to replace them periodically. Among the advantages of carbon are ready reactivity with many organic substances, large reactive surface to mass ratios, and light weight.

Ultraviolet Irradiation Ultraviolet irradiation is a method of deodorization that can be very effectively exploited in the Space Station. The principle behind this method is the interaction of radiation and chemical reaction. Single atom oxygen is produced through ultraviolet bombardment. These single oxygen atoms bond to other molecules, thereby oxidizing them. Humans are insensitive to oxidized molecules; therefore, the offending substance is rendered nonodorous. In contrast to other methods, where air flow is essential, air must remain for some time (4-6 seconds) in the irradiation chamber before being returned to circulation. Irradiation chambers can be used in sequence with electrostatic and dry scrubbing methods to produce a highly effective combination filtration/purification system.

The first recommendations (51- 54) are guidelines for the necessary airflow to maintain air of perceived high quality. These recommendations are based on Summer (1971). The air flow values that follow are minimum values and assume that "fresh air" (air that has passed through the filtration system) will be entered into the area in question. These volumes will have to be increased, if necessary, to keep concentrations of odorous substances below detectable levels in normal operating situations, or to bring concentrations below the threshold level within 5 minutes after the production of the substance has ceased.

Recommendations

51. Holding interior volume constant, waste management facilities, due to their public nature, require 12-15 air changes per occupant per hour. For a single user facility of approximately 100 ft^3, this implies movement of 100 ft^3 every 4 to 5 minutes, or 20-25 ft^3/min.

52. Crew quarters, being private offices/living areas, require approximately 15 ft^3/min. of air flow, although this value should be adjustable to suit individual preferences.

53. Work stations, which approximate Summer's (1971) "general offices," require 15 ft^3/min per person.

54. Public areas (general meeting, eating, or comparable areas) should have fresh air flows of 25-40 ft^3/ min per person.

55. A three-part air filtration system is suggested.

Part 1. The first phase of the air purification/odor removal process should include some type of electrostatic process of particulate removal. Particles of size .001 micron or larger are to be attracted through this system. Charged filters can be integrated with this system to ensure removal of particles through physical or electrostatic retention. Filters will have to be cleanable/replaceable by astronauts in flight. Arrangements must be made for particulates to be removed from the filters for ejection or other disposal without recontamination of the air within habitable areas of the Space Station.

Part 2. A subsequent phase of air decontamination should include chemical filtration, or dry scrubbing. Dry-scrubbing techniques utilizing activated carbon are most effective and economic with relatively low levels of contaminants. Carbon has its highest affinity for retaining hydrocarbon compounds, and thus is quite efficient in removing body and food odor (more than one third of such molecular compounds by weight). Such filtration methods should allow for long use between filter changes, and capacity for astronauts to change filters during flight. An ideal system would allow filters to be chemically scoured, with contaminants ejected as refuse or recycled into some other system.

Part 3. Ultraviolet irradiation should be explored as the third step in the decontamination process. The preferred wavelengths of radiation are less than 2000 Angstroms (A) with a desired wavelength of 1849A. Air should remain in the radiation chamber for 4-6 seconds, and should be fully and directly irradiated. The size of the chamber depends on the expected air flow through the chamber. Ozone produced by the radiation chamber should not exceed .05 ppm in habitable areas, and no additional radiation should enter habitable areas through direct or indirect passage through the chamber. This chamber will need to be cleaned or replaced infrequently; this operation must be accomplished by astronauts without undue danger from corrosive/contaminant material, or recontamination of air supply. Neoprene and vinyl linings have been shown to be of high corrosion resistance in such radiation chambers, and should be utilized where anodized aluminum (and the resulting layer of aluminim oxide) will not allow sufficient corrosion protection.

56. Exposed surfaces must be cleanable to eliminate residual contaminants that might give rise to toxic or unpleasant odors.

57. Personal hygiene facilities should make it possible for each astronaut to wash on an ad-lib basis and undertake full body cleaning at least twice a week.

58. Astronauts will require fresh changes of clothes at least twice a week.

Supplemental Mechanisms for Achieving Privacy

Architectural and design interventions are not the only approaches to accommodating astronauts' privacy needs. Certain selection and training procedures and the development of appropriate social norms can help groups of astronauts achieve desired levels of privacy. These procedures are not substitutes for the design recommendations set forth in the earlier sections of this report, but they do serve as useful adjuncts or supplements.

Selection

Personal space requirements vary as a function of the individual. Consequently, one selection consideration might be the level of privacy that a person characteristically seeks. Another would be forming crews of individuals whose personalities intermesh in such a way that they find relatively little need to "escape" from one another.

Studies of sex or gender-related variables suggest that males have greater personal space requirements than do females, and people tend to maintain greater distances from males than from females. Also, people tend to require less personal space when in the presence of a person of the opposite sex than when in the presence of someone of the same sex (Altman, 1975; Raybeck, 1987). In terms of privacy considerations, at least, there may be certain advantages to all female or mixed-gender crews.

In general, poor psychological adjustment is associated with a distortion of privacy needs. Compared to well-adjusted people, poorly-adjusted people tend to have unusual personal space requirements (Altman, 1975; Cavillin & Houston, 1980). Rejecting deviant or maladjusted people is likely to reduce privacy problems as well as help solve problems in other social and behavioral areas.

Groups that are composed in such a way that the different members' personal interests and needs complement or mesh with one another can get along with less space than can groups whose members' motives clash or conflict (Altman, 1973; Altman & Haythorn, 1965, 1967a, 1967b; Altman, Taylor & Wheeler, 1971; Haythorn, 1970, 1973; Haythorn & Altman, 1967; Haythorn, Altman & Myers, 1966). Under conditions of isolation and confinement, people with compatible needs direct their hostilities or antagonisms towards "outsiders," whereas people with conflicting needs express their hostilities towards one another (Smith & Haythorn, 1972),

and it may be this intragroup tension that increases personal space requirements. This interpretation is suggested by findings that the members of groups that are characterized by positive, friendly, harmonious relations are willing to be more accessible to one another than are members of groups that are characterized by tensions or conflicts (Hayduk, 1978). Thus, selecting people who have compatible needs is likely to increase tolerance for close quarters.

Training

Several training procedures can help compensate for relatively low levels of privacy aboard the Space Station. First, as noted in the preceding section, people are more accepting of close confines when the group is characterized by harmonious relations than when it is characterized by conflict or hostility. Thus, training the crew in interpersonal relations may alleviate some of the problems of crowding. Second, it is important that crewmembers develop a clear understanding of privacy levels aboard the Space Station. People who expect conditions to be cramped or crowded seem to need less personal space than do people who have unrealistic expectations (Baum & Greenberg, 1975). Third, crew preparation should include training in the use of definable and redefinable environments and in the use of interpersonal distancing mechanisms.

A high level of physiological activation or arousal is associated with crowding, and control over activation decreases the perception of crowding and hence limits some of crowding's undesirable effects. Since meditation provides control over arousal, it may be a useful mechanism for helping astronauts to function well within the Space Station's close confines. As Raybeck (1987) points out:

> Among other cultures... the Japanese have demonstrated the utility of meditation as a means of obtaining relief from stressful circumstances including those due to crowding...there is good evidence from studies conducted in the United States and elsewhere that meditation greatly increases alpha rhythms associated with restfulness and that it can provide quick relief from stressors...Meditation techniques are easily learned and represent a very effective means for providing, in the absence of physical privacy, a form of psychological privacy that should subtantially reduce the stress of life in a crowded environment.

Social Norms

As noted in an earlier report on Space Station privacy (Harrison, Sommer, Struthers & Hoyt, 1986), social rules which prescribe appropriate interpersonal distances affect privacy. Examples of such rules are the rule that one person should not bother another person who appears to be dozing or engrossed in work, or the rule that one should maintain a respectful distance from a stranger or a person who is of substantially higher rank. Research by Altman and his associates highlights the importance of such norms in isolated and confined environments (Altman, 1973; Altman, Taylor & Wheeler, 1971; Taylor, Wheeler & Altman, 1968; Taylor, Altman, Wheeler & Kushner, 1969). It was found that two person groups or dyads that remained intact under conditions of isolation and confinement evolved social norms regarding personal space and territories early in the course of the confinement period. Members of the dyads that did not complete the simulated mission were initially uninterested in such norms but frantically tried to establish them as social tensions mounted.

In a related study, MacDonald and Oden (1973) observed a large number of couples that were crammed into a small dormitory facility while undergoing Peace Corps training. Although some signs of tension appeared, these couples maintained high intellectual and social standards. One factor contributing to this group's success was that group members immediately adopted and followed rules against improper forms of social intrusion such as looking at other people while they were getting dressed and listening in on other people's arguments.

Recommendations

59. Do not select individuals with unusual space requirements.

60. Composing crews in such a way that the members have compatible needs will alleviate problems in the area of privacy.

61. Training in interpersonal relations and relaxation techniques will help reduce individual privacy requirements.

62. Steps should be taken to encourage the establishment of clear group norms regarding the use of different areas, appropriate and inappropriate distancing behaviors, and the need for individual crew members to withdraw from the group.

63. The scheduling of "alone time" removes the onus of temporarily retreating from the group (Stuster, 1986).

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